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Taxonomy & Inventories

First report of an intersex individual of the click beetle *Pectocera fortunei* (Elateridae) and additional cases of gynandromorphism in Coleoptera (Lucanidae, Scarabaeidae)

Donguk Kim[‡,§], Sangeun Hyun[‡], Kwang Shik Choi[‡,§]

‡ Department of Biology, College of Natural Sciences, Kyungpook National University, Daegu, Republic of Korea
§ School of Life Sciences, BK21 FOUR KNU Creative BioResearch Group, Kyungpook National University, Daegu, Republic of Korea

Corresponding author: Kwang Shik Choi (ksc@knu.ac.kr)

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Abstract

Background

The occurrence of individuals exhibiting both male and female phenotypes is a rare phenomenon observed across various insect orders.

New information

This study documents the first case of an intersex individual of *Pectocera fortunei* Candèze, 1873, from the Korean Peninsula, including behavioural findings. This is the first report of such a phenomenon in the family Elateridae. Two cases of gynandromorphism are also described: one in *Dorcus titanus castanicolor* (Motschulsky, 1861) (Lucanidae) and the other in *Trypoxylus dichotomus septentrionalis* (Kôno, 1931)

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(Scarabaeidae). The former is a new record for this subspecies. An updated list of intersex and gynandromorphic beetles is also provided.

Keywords

sexual dimorphism, stag beetle, rhinoceros beetle, *Dorcus*, *Trypoxylus*, Korea

Introduction

In sexually dimorphic species, a rare phenomenon has been observed in which certain arthropod individuals exhibit both male and female phenotypic characteristics. Although this phenomenon is uncommon, it has been documented across most insect orders (Narita et al. 2010, Lightburn et al. 2022). Such individuals can be classified into two types: gynandromorphs, in which distinct boundaries separate male and female parts and intersexes, in which such boundaries are ambiguous or absent (Narita et al. 2010, Fusco and Minelli 2023). These individuals exhibit diverse and unique morphological characteristics, with male and female phenotypes clearly separated bilaterally or transversally or mixed in a mosaic pattern (Fusco and Minelli 2023).

The phenomena of intersex and gynandromorphism have various causes and can be classified according to different criteria depending on the characteristics of each case or the researcher's approach. Sex determination and differentiation result from the complex interplay of genetic, developmental and environmental factors. These phenomena may be induced by distal factors, such as hybridisation or parasitic infection or proximal factors, such as the missing expression of a key sex-determining gene (Fusco and Minelli 2023).

In the order Coleoptera, several cases of intersex and gynandromorphic individuals have been reported, with most records belonging to the family Scarabaeidae (Narita et al. 2010). However, since the first documented case of gynandromorphism in Coleoptera by Wickham (1903), no such cases have been identified in click beetles. In this study, we report the first case of an intersex individual of *Pectocera fortunei* Candèze, 1873, discovered in the Korean Peninsula, marking the first record of such a case within the family Elateridae. Moreover, we report two cases of gynandromorphism: one in *Dorcus titanus castanicolor* (Motschulsky, 1861) (Lucanidae) and the other in *Trypoxylus dichotomus septentrionalis* (Kôno, 1931) (Scarabaeidae). The former case represents a new record for this subspecies. To provide an updated checklist of intersex and gynandromorphic cases in Coleoptera, we combined previous reports with our findings, resulting in the recognition of 31 species across eight families.

Materials and methods

An intersex individual of *P. fortunei* was collected at Chungnam National University (CNU, Daejeon, Korea), through a light trap survey in May 2023 (Fig. 1). Two

gynandromorphs (*D. titanus castanicolor* and *T. dichotomus septentrionalis*) were found in a private insect breeding facility in July 2019 and November 2019, respectively.

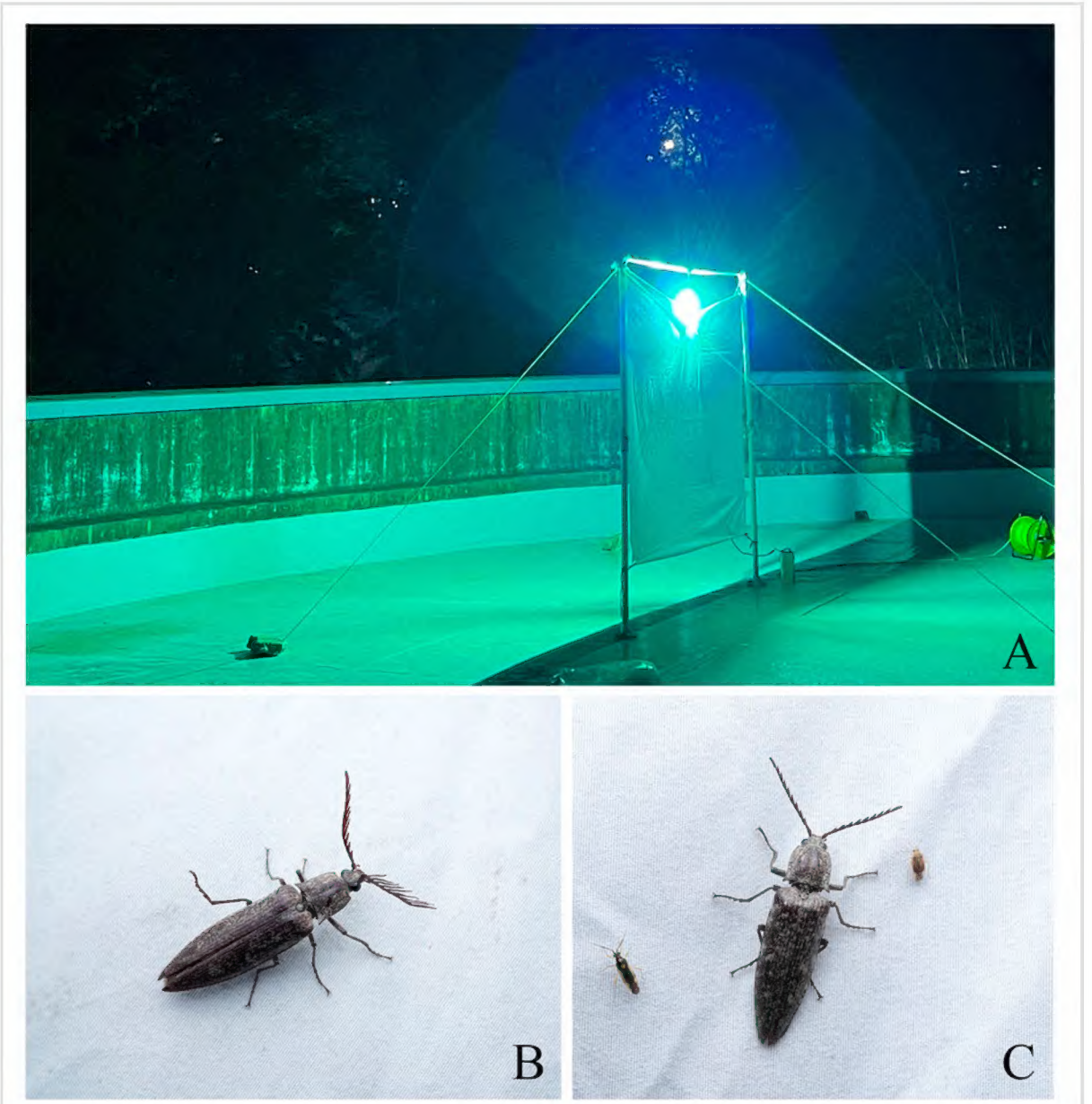

Figure 1. doi

Field photograph of *Pectocera fortunei* at CNU. **A** Light trap installation setup; **B** Intersex individual of *Pectocera fortunei* attracted to the light trap; **C** Normal female individual of *Pectocera fortunei* attracted to the light trap.

The genitalia of all specimens were dissected using forceps and the surrounding tissues were removed by treating them with a 10% potassium hydroxide (KOH) solution for 50 min. The specimens were preserved as dry specimens and the genitalia were stored in microtubes containing glycerine for long-term preservation.

External morphological characteristics and genitalia were examined and photographed using an Olympus SZX16 stereomicroscope (Olympus, Tokyo, Japan), an Olympus OMD EM10 Mark II digital camera and a Michrome 16 CMOS camera (Tucsen, Fujian, China). Adobe Photoshop 21.2.0 (Adobe Systems Inc.) was used to edit the captured images. The specimens are deposited in the Laboratory of Animal Systematics and Taxonomy, School of Life Sciences, College of Natural Sciences, Kyungpook National University (KNU, Daegu, Korea).

The behavioural observation of *P. fortunei* was conducted by introducing an intersex individual and a typical female individual into a single breeding case lined with tissue paper (Suppl. material 1).

The updated list of intersex and gynandromorphic cases in Coleoptera was compiled by reviewing the literature provided by Narita et al. (2010), incorporating our findings, previously missing studies and recent literature.

Taxon treatments

Pectocera fortunei Candèze, 1873

Materials

a. genus: *Pectocera*; specificEpithet: *fortunei*; scientificNameAuthorship: Candèze, 1873; country: South Korea; locality: CNU, Gung-dong, Yuseong-gu, Daejeon, Sang Eun Hyun leg.; eventDate: 25.V.2023; sex: 1 intersex; basisOfRecord: Preserved Specimen; occurrenceID: 52C9BE44-7BEA-5418-BC0A-7598D646DA89

b. genus: *Pectocera*; specificEpithet: *fortunei*; scientificNameAuthorship: Candèze, 1873; country: South Korea; locality: CNU, Gung-dong, Yuseong-gu, Daejeon, Sang Eun Hyun leg.; sex: 5 females; basisOfRecord: Preserved Specimen; occurrenceID: DCF7A291-7B77-54A4-A0F3-BF14635E96E8

c. genus: *Pectocera*; specificEpithet: *fortunei*; scientificNameAuthorship: Candèze, 1873; country: Japan; locality: Aseri, Kyotanba Town, Kyoto Pref., 14.VI.2014, Satoshi Kubo leg.; sex: 1 male, 1 female; basisOfRecord: Preserved Specimen; occurrenceID: EE66458A-FC82-55DB-AAB4-CB64DBE9B5E7

Morphology of the intersex Pectocera fortunei: The body overall exhibits female traits, except for the antennae (Figs 2, 3, 4). The head displays relatively small eyes and mandibles resembling those of a typical female (Fig. 3). The lateral margins of the pronotum are convex and arcuate, narrowing towards the posterior angles, as typically seen in females (Fig. 3). The antennae are pectinate, similar to those of a typical male and asymmetrical between the left and right sides, with nine irregularly transformed flagellomeres (Fig. 4). The genitalia are fully developed and identical to a typical ovipositor (Fig. 5).

Behavioral interactions between an intersex and a typical female: To examine the behavioural interactions between an intersex individual and a typical female, one of each was placed in a single breeding case for observation. As a result, they exhibited only biting and aggressive behaviour, with no mating behaviour observed.

Notes

In *P. fortunei*, the prominent male sexual characteristics include pectinate antennae, relatively large eyes and a narrow pronotum (Figs 2, 3). In the observed specimen, only female sexual characteristics were displayed in all body parts, including the genitalia, except for the antennae (Figs 2, 3, 4, 5). The antennae exhibited a pectinate

pattern similar to that of a male. However, the nine flagellomeres appeared as if the female flagellomeres had been transformed into a slender and elongated shape like those of a male (Fig. 4). Consequently, it was ambiguous to clearly identify this as a distinct male trait; thus, the specimen was classified as intersex. This is the first record for this family.

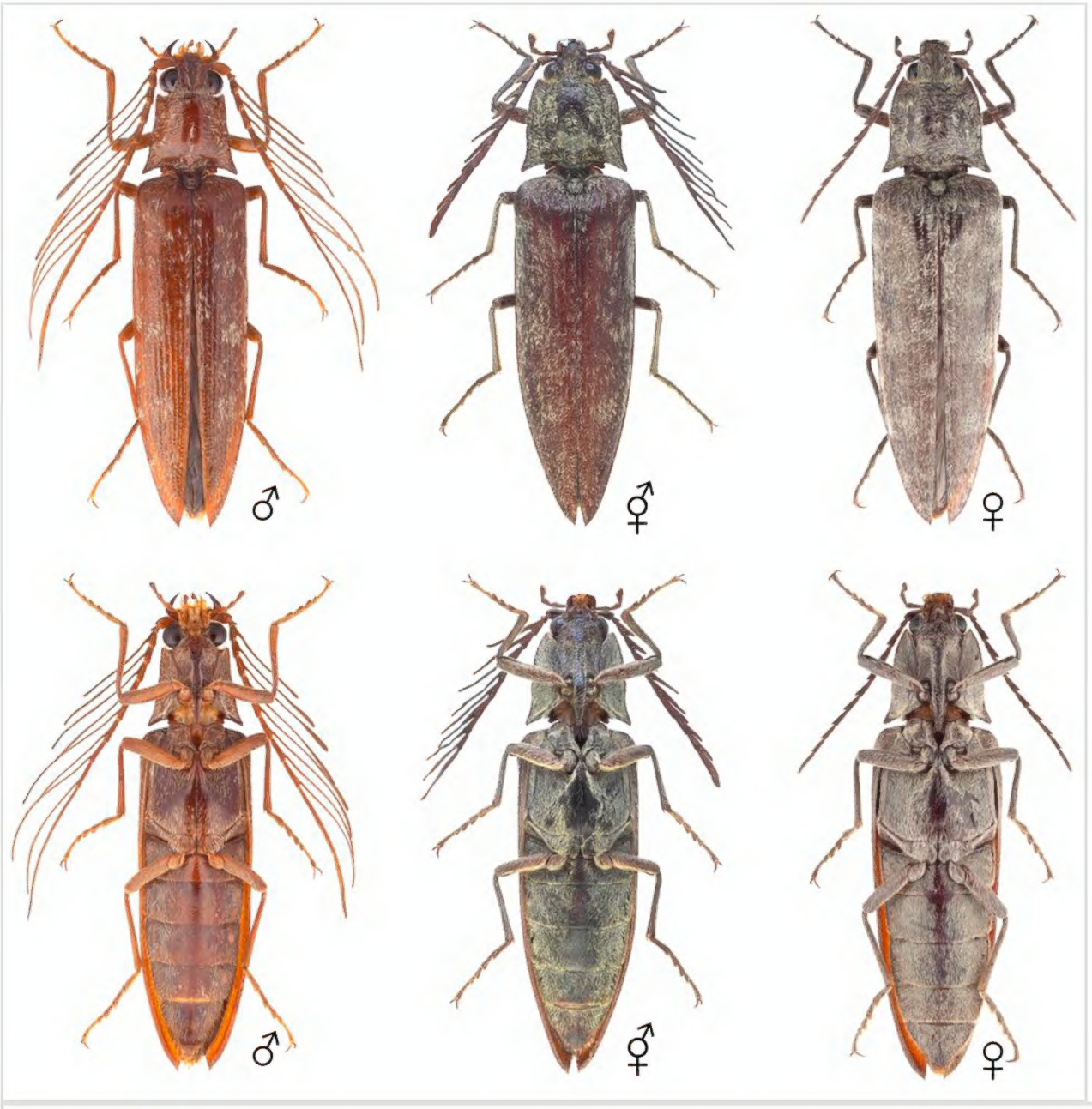

Figure 2. doi

Habitus of *Pectocera fortunei*, dorsal (above) and ventral (below) views. From left: male, intersex and female.

Dorcus titanus castanicolor

Materials

a. genus: *Dorcus*; specificEpithet: *titanus castanicolor*; scientificNameAuthorship: (Motschulsky, 1861); country: South Korea; locality: Hyeongsu Kim leg.; eventDate: VII. 2019 (breed); sex: 1 gynandromorph; basisOfRecord: Preserved Specimen; occurrenceID: 09268E7D-25D3-5F13-A399-753809D0B384

b. genus: *Dorcus*; specificEpithet: *titanus castanicolor*; scientificNameAuthorship: (Motschulsky, 1861); country: South Korea; stateProvince: Chungcheongbuk-do; locality:

Chupungryeong, Chupungryeong-myeon, Yeongdong-gun, Seung Mo Lee Coll.; eventDate: 29.VII.1972; sex: 1 female; basisOfRecord: Preserved Specimen; occurrenceID: 9E55012A-86F6-5022-A53D-93EF9D0DF949

Figure 3. doi

Pronotum and head of *Pectocera fortunei*, dorsal (above) and ventral (below) views. From left: male, intersex and female.

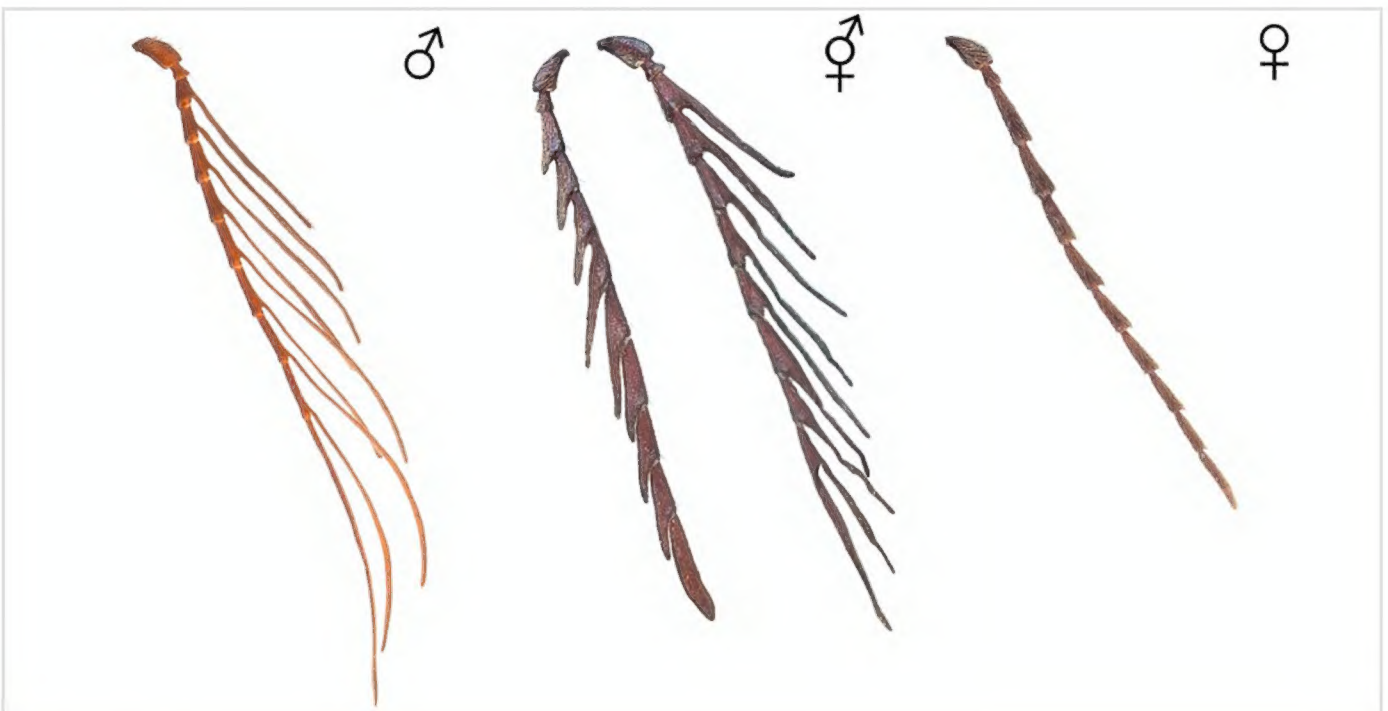

Figure 4. doi

Antennae of *Pectocera fortunei*. From left: male, intersex and female.

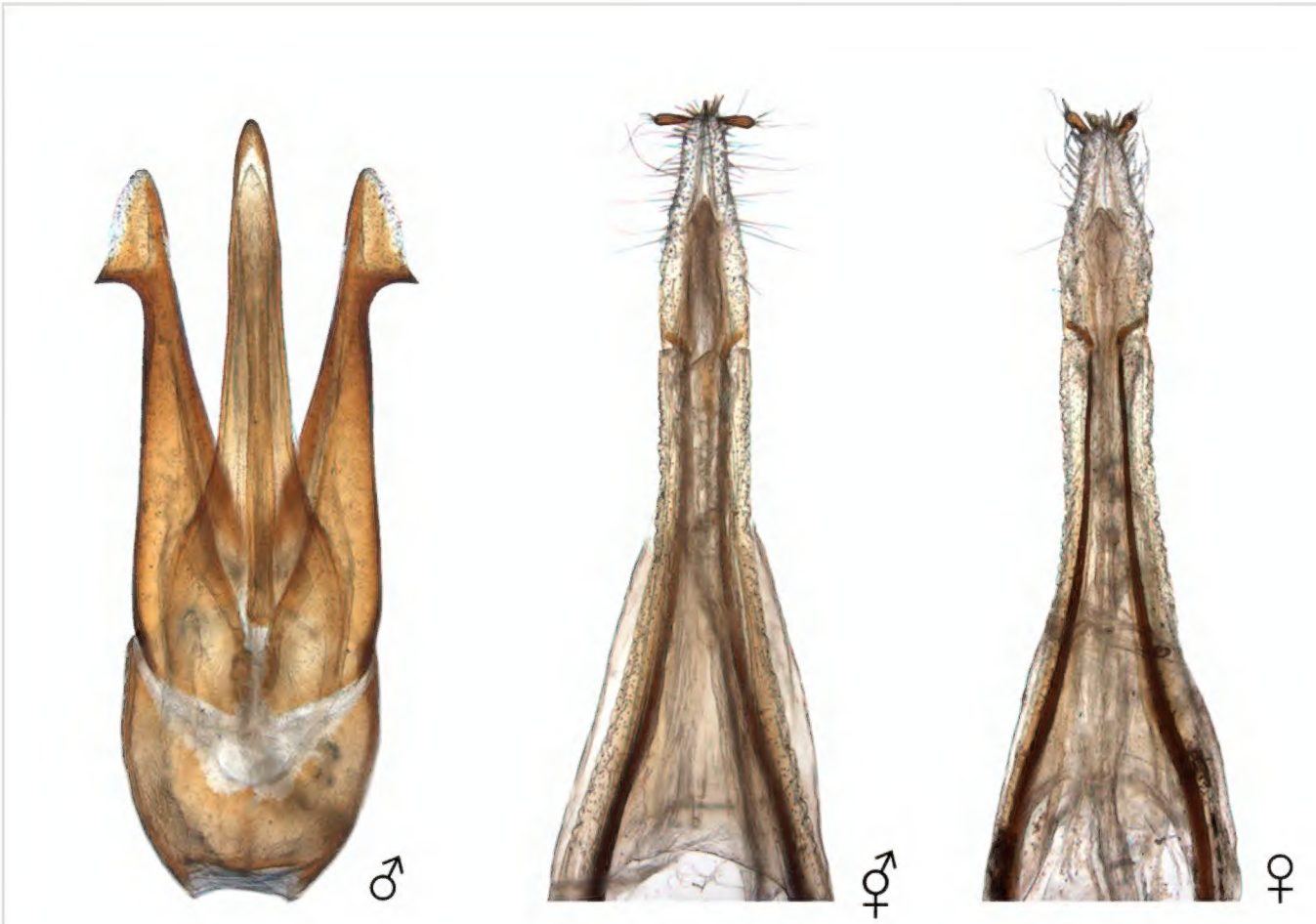

Figure 5. doi

Genitalia of *Pectocera fortunei*. From left: male, intersex and female.

c. genus: *Dorcus*; specificEpithet: *titanus castanicolor*; scientificNameAuthorship: (Motschulsky, 1861); country: South Korea; stateProvince: Jeollanam-do; locality: Is. Jindo, Jukrim-ri, Imhoe-myeon, Jindo-gun, Donguk Kim leg.; eventDate: 4.VIII.2020; sex: 1 male, 1 female; basisOfRecord: Preserved Specimen; occurrenceID: 95F2493E-FB09-5626-8E45-ECAC995F39D8

Morphology of the gynandromorph Dorcus titanus castanicolor: The body primarily exhibits female traits (Fig. 6). The head shows asymmetrical dimorphism, with the left side resembling a male and the right side resembling a female (Fig. 7). The surface of the head appears irregular, featuring patchy punctures. Male-type punctures are predominantly located on the left side, while female-type punctures are predominantly located on the right (Fig. 7). The mandibles are asymmetrical, with the left side more developed. The left antenna is slightly larger (Fig. 7). In the central area of the left side of the pronotum, male-type punctures appear in a patchy pattern (Fig. 7). The legs exhibit only female characteristics (short, with a rather wide protibia) (Fig. 6). The genitalia are fully developed and identical to a typical ovipositor (Fig. 8).

Notes

In *D. titanus castanicolor*, the prominent male sexual characteristics include well-developed mandibles, a non-projected canthus, a subrectangular pronotum and relatively long tarsi (Fig. 6). In the observed specimen, most body traits, including the

legs and genitalia, exhibited female morphological characteristics. However, irregular patches of both male-type and female-type punctures were noted on the head and pronotum (Figs 6, 7, 8). Hence, this specimen was classified as a gynandromorph. This is the first record for this subspecies.

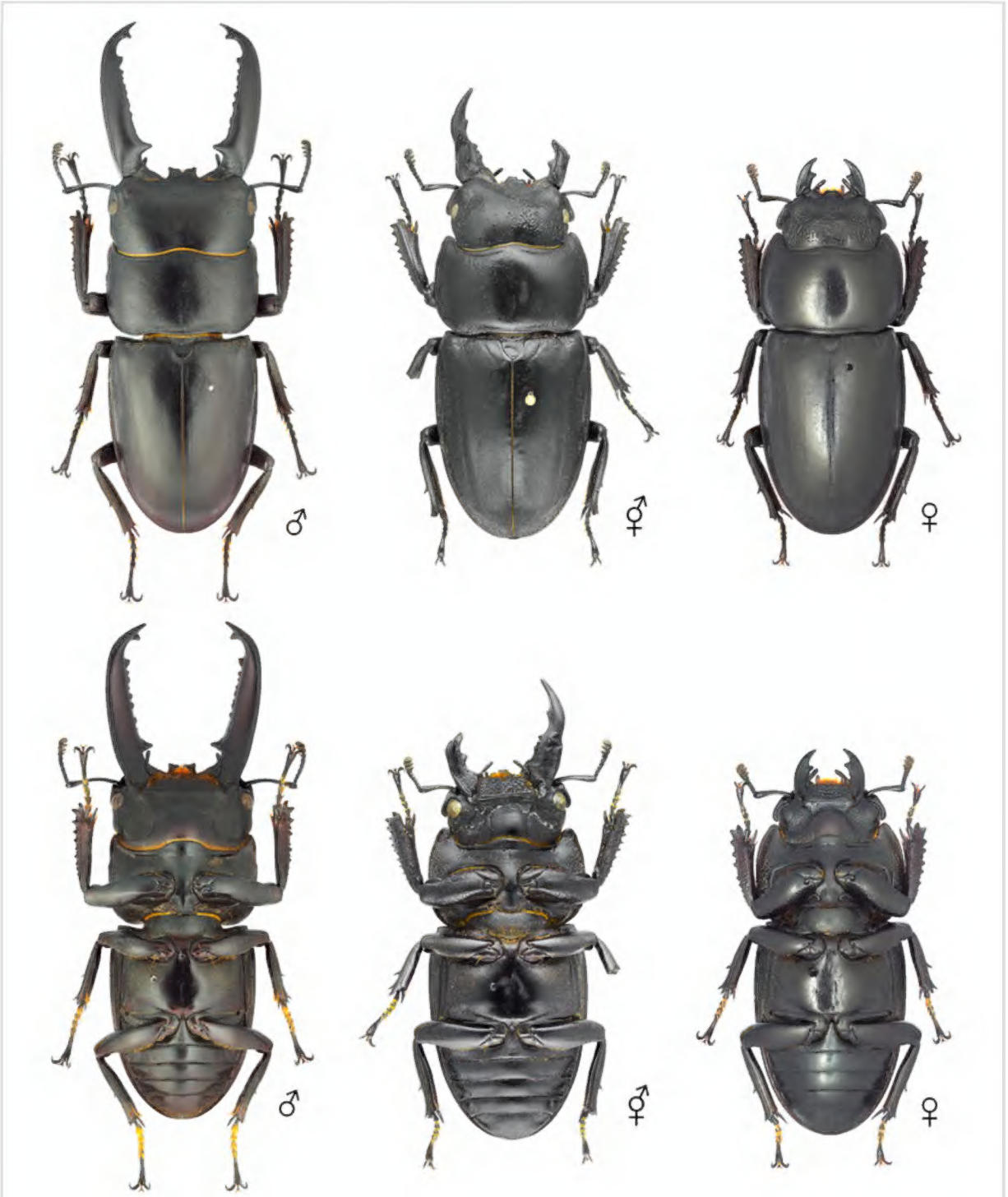

Figure 6. doi

Habitus of *Dorcus titanus castanicolor*, dorsal (above) and ventral (below) views. From left: male, gynandromorph and female.

Trypoxylus dichotomus septentrionalis (Kôno, 1931)

Materials

a. genus: *Trypoxylus*; specificEpithet: *dichotomus septentrionalis*; scientificNameAuthorship: (Kôno, 1931); country: South Korea; locality: Songyong Lee leg.; eventDate: 30.XI.2019

(breed); sex: gynandromorph; basisOfRecord: Preserved Specimen; occurrenceID: BB0266CB-A621-5217-9808-8AFA3591AFA7

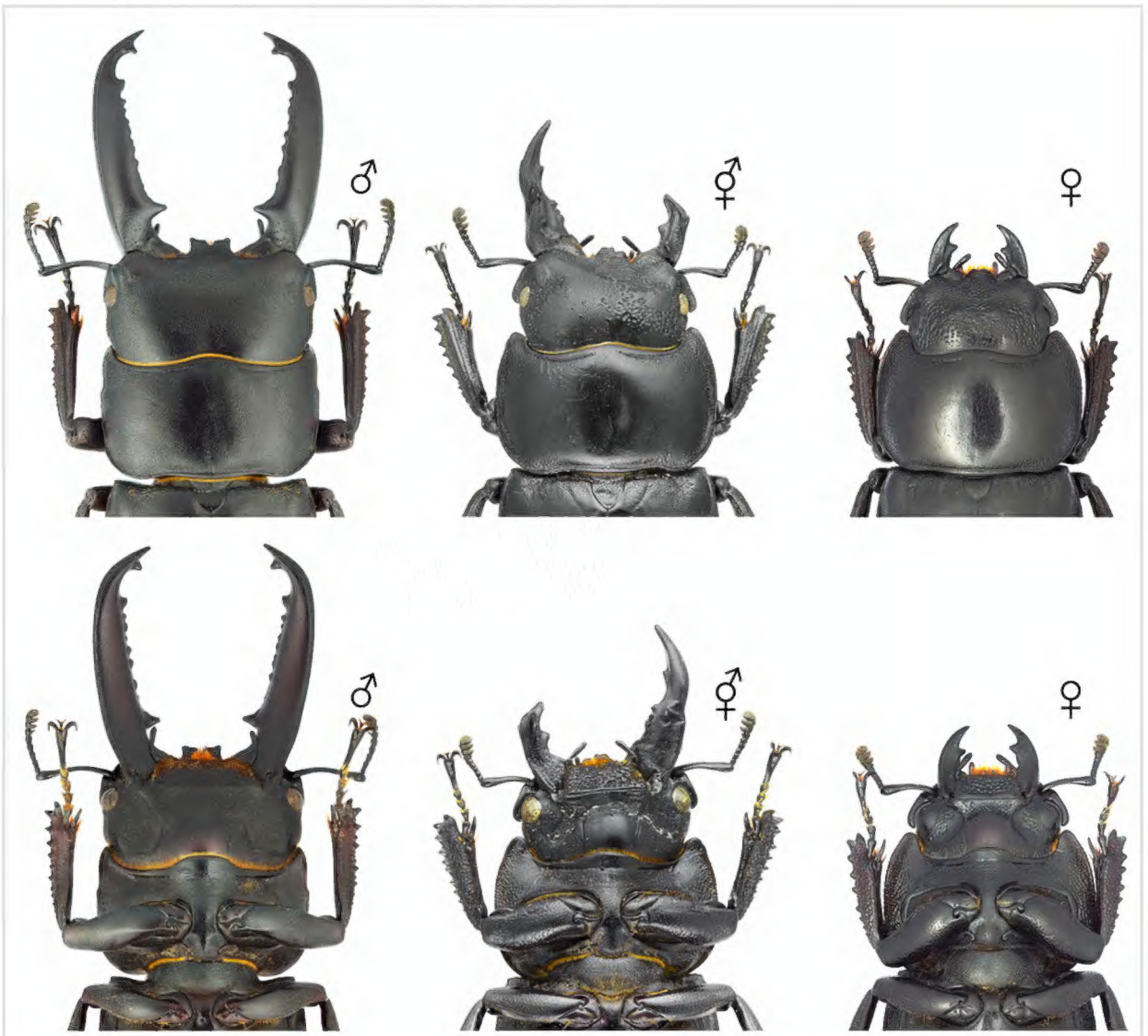

Figure 7. doi

Pronotum and head of *Dorcus titanus castanicolor*, dorsal (above) and ventral (below) views. From left: male, gynandromorph and female.

Figure 8. doi

Genitalia of *Dorcus titanus castanicolor*. From left: male, gynandromorph and female.

b. genus: *Trypoxylus*; specificEpithet: *dichotomus septentrionalis*; scientificNameAuthorship: (Kôno, 1931); country: South Korea; stateProvince: Jeollanam-do; locality: Is. Jindo, Jukrim-ri, Imhoe-myeon, Jindo-gun; eventDate: 4.VIII.2020; sex: 1 male, 1 female; basisOfRecord: Preserved Specimen; occurrenceID: D3195208-3391-57AF-A0E0-BCAD19B62715

c. genus: *Trypoxylus*; specificEpithet: *dichotomus septentrionalis*; scientificNameAuthorship: (Kôno, 1931); country: South Korea; stateProvince: Jeju-do; locality: Is. Jejudo, Daepo-dong, Seogwipo-si; eventDate: 29.VII.2018; sex: 1 female; basisOfRecord: Preserved Specimen; occurrenceID: 394BE149-33BB-5433-9E13-1FFA34CF3510

Morphology of the gynandromorph Trypoxylus dichotomus septentrionalis: The body exhibits a bilateral division of male and female phenotypes, with the left side displaying female characteristics and the right displaying male characteristics (Fig. 9). The head primarily exhibits female traits, but a subrectangular horn is present on the right side of the frons (Fig. 10). The pronotum resembles that of a male, with an incomplete horn on the left side and scattered punctures and pubescence appearing as spots on the surface (Fig. 10). The elytra display female characteristics (dense pale-yellow pubescence) on the left side, while the right side exhibits male characteristics (lacking dense pale-yellow pubescence) (Fig. 9). The legs exhibit a mixture of male and female traits. The protibiae on both sides display female characteristics (rather short and wide, with dense and wide punctures on the surface), but the claws are male-like. The mesotibiae and mesotarsi on both sides display female characteristics (rather short, with two external teeth on the outer margin of the mesotibia). The metatibia and metatarsus are asymmetrical, with the left side displaying female characteristics (a well-developed bidentate apex and a rather short tarsus), while the right side possesses both male (a rather narrow metatibia and a long metatarsus) and female characteristics (two external teeth on the outer margin of the metatibia). The femora overall exhibit male characteristics, except for the left profemur and left metafemur, which display female characteristics (rather wide, with the anterior margin of the profemur covered in dense yellow pubescence) (Fig. 9). The sternites exhibit asymmetry, with a narrow intersegmental space on the left and a broader one on the right (Fig. 11). The genitalia resemble a male aedeagus, but are asymmetrical between the left and right sides, abnormally developed and have paramere apices that are outwardly spread (Fig. 12). Additionally, eight eggs were found alongside the genitalia (Fig. 12).

Notes

In *T. dichotomus septentrionalis*, the primary male sexual characteristics include a well-developed horn on the head and pronotum, a relatively smooth pronotal surface and an elytral surface lacking dense pale-yellow pubescence. In the observed specimen, the body overall displayed a bilateral separation of male and female phenotypes (Figs 9, 10, 11), but the legs exhibited a complex mixture of male and female traits. Based on these male and female morphological distinctions, this specimen was classified as a gynandromorph.

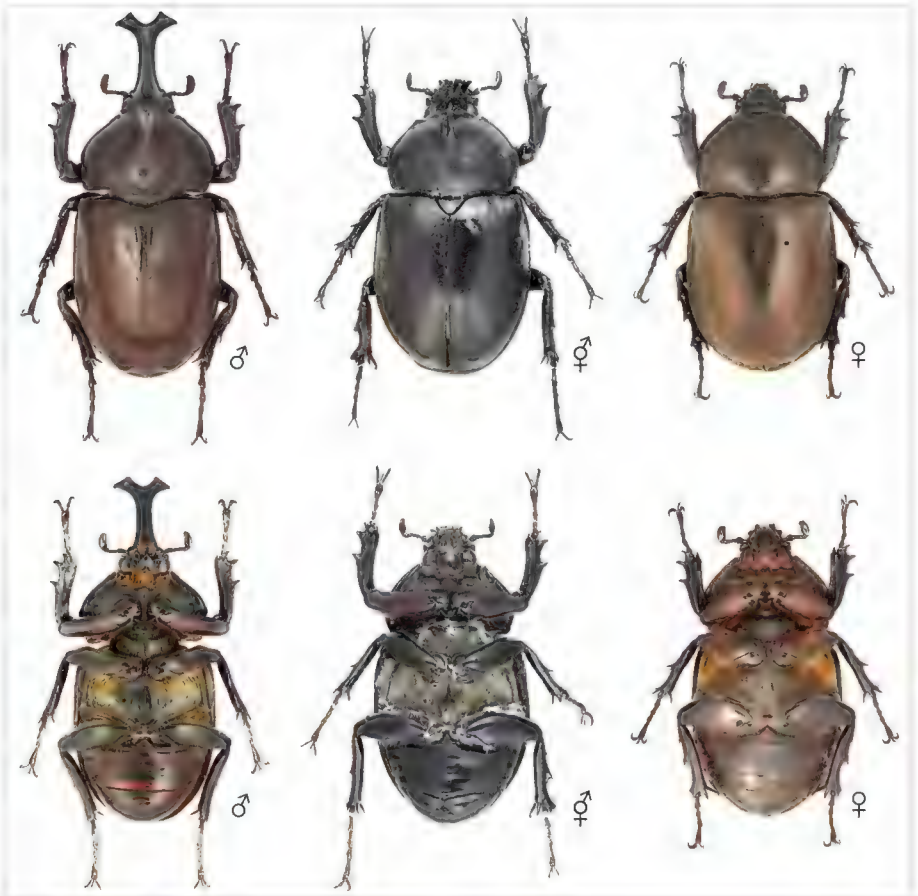

Figure 9. doi

Habitus of *Trypoxylus dichotomus septentrionalis*, dorsal (above) and ventral (below) views. From left: male, gynandromorph and female.

Figure 10. doi

Pronotum and head of *Trypoxylus dichotomus septentrionalis*. From left: male, gynandromorph and female.

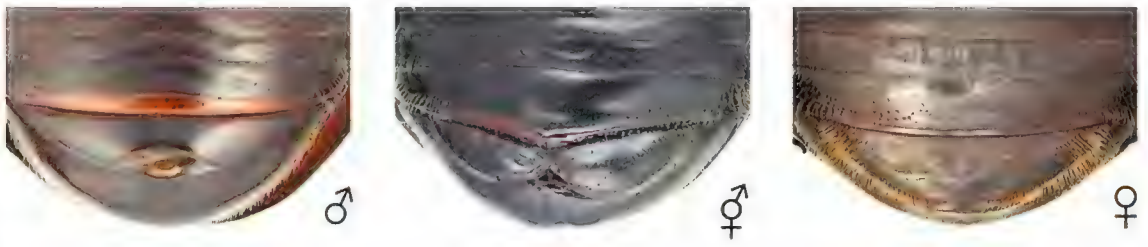

Figure 11. doi

Abdominal sternites of *Trypoxylus dichotomus septentrionalis*. From left: male, gynandromorph and female.

Figure 12. doi

Genitalia and egg of *Trypoxylus dichotomus septentrionalis*. Above: normal individual; Below: gynandromorph.

Analysis

Updated list and composition of sexual anomaly cases in Coleoptera

The compilation of our research findings and updation of intersex and gynandromorphic cases in Coleoptera revealed a total of 31 species across eight families (Table 1). Amongst these, the family Scarabaeidae was found to have the largest proportion of cases (42%), followed by Lucanidae (23%), Cerambycidae (13%) and Carabidae (10%) (Fig. 13).

Table 1.

Updated list of intersex and gynandromorph cases in Coleoptera. New records are indicated with an asterisk (*).

N	Family	Species	References
1	Carabidae	*Carabus nemoralis*	Hartkorn (1982)
2		*Carabus* (*Leptocarabus*) *arboreus*	Morishita (1991)
3		*Pterostichus* (*Nialoe*) *musahiensis*	Kashara and Karube (1995)
4	Cerambycidae	*Akimerus schaefferi*	Auvray and Auvray (1998)

N	Family	Species	References
5		*Ergates faber*	Balazuc (1952)
6		*Leptura rubra*	Weber (1913)
7		*Rhagium mordax*	Starzyk (1984)
8	Chrysomelidae	*Cerotoma facialis*	Ruppel (1971)
9	Curculionidae	*Euplatypus hintzi*	Beaver (2000)
10	Elateridae*	*Pectocera fortunei**	This study
11	Lucanidae	*Dorcus titanus castanicolor**	This study
12		*Dorcus titanus pilifer*	Okushima et al. (2023)
13		*Dorcus titanus sakishimanus*	Ogata (1993)
14		*Lucanus elaphus*	Wickham (1903)
15		*Lucanus maculifemoratus*	Hayashi (1987), Hayashi (1993), Tanikado (1994), Noumi and Kuranishi (2010)
16		*Neolucanus insularis*	Sakaino and Kawata (1995)
17		*Neolucanus insulicola insulicola*	Matsuoka (2013)
18		*Prosopocoilus hachijoensis*	Inoue (2013)
19		*Prosopocoilus inclinatus inclinatus*	Hirayama and Shimizu (2012)
20	Salpingidae	*Boros discicollis*	Spilman (1953)
21	Scarabaeidae	*Cotinis mutabilis*	Deuve (1992)
22		*Dasylepida ishigakiensis*	Tanaka et al. (2006)
23		*Dicranocephalus wallichii wallichii*	Mizunuma (2002)
24		*Goliathus cacicus*	Ture (2001)
25		*Golofa tersander*	Ratcliffe (1989)
26		*Megasoma elephas*	Dechambre (1987)
27		*Megasoma occidentale*	Blackaller-Bages and Gado-Castillo (1990)
28		*Melolontha japonica*	Kurosawa (1969)
29		*Paratrichius doenitzi*	Kurosawa (1993); Haga (1997)
30		*Polyphylla fullo*	Vasko (2008)
31		*Polyphylla laticollis*	Kurosawa (1993)
32		*Protaetia exasperata exasperata*	Shuida (2020)
33		*Trypoxylus dichotomus septentrionalis*	Kurosawa (1979), Sakurai (2013), This study

Discussion

In arthropods, individuals exhibiting mixed male and female traits have been reported in various insect and non-insect taxa under both natural and experimental conditions (Narita et al. 2010). However, the molecular distinction between gynandromorphs and

intersex individuals often remains unclear (Narita et al. 2010). Therefore, in this study, generally accepted definitions were used to differentiate between these conditions.

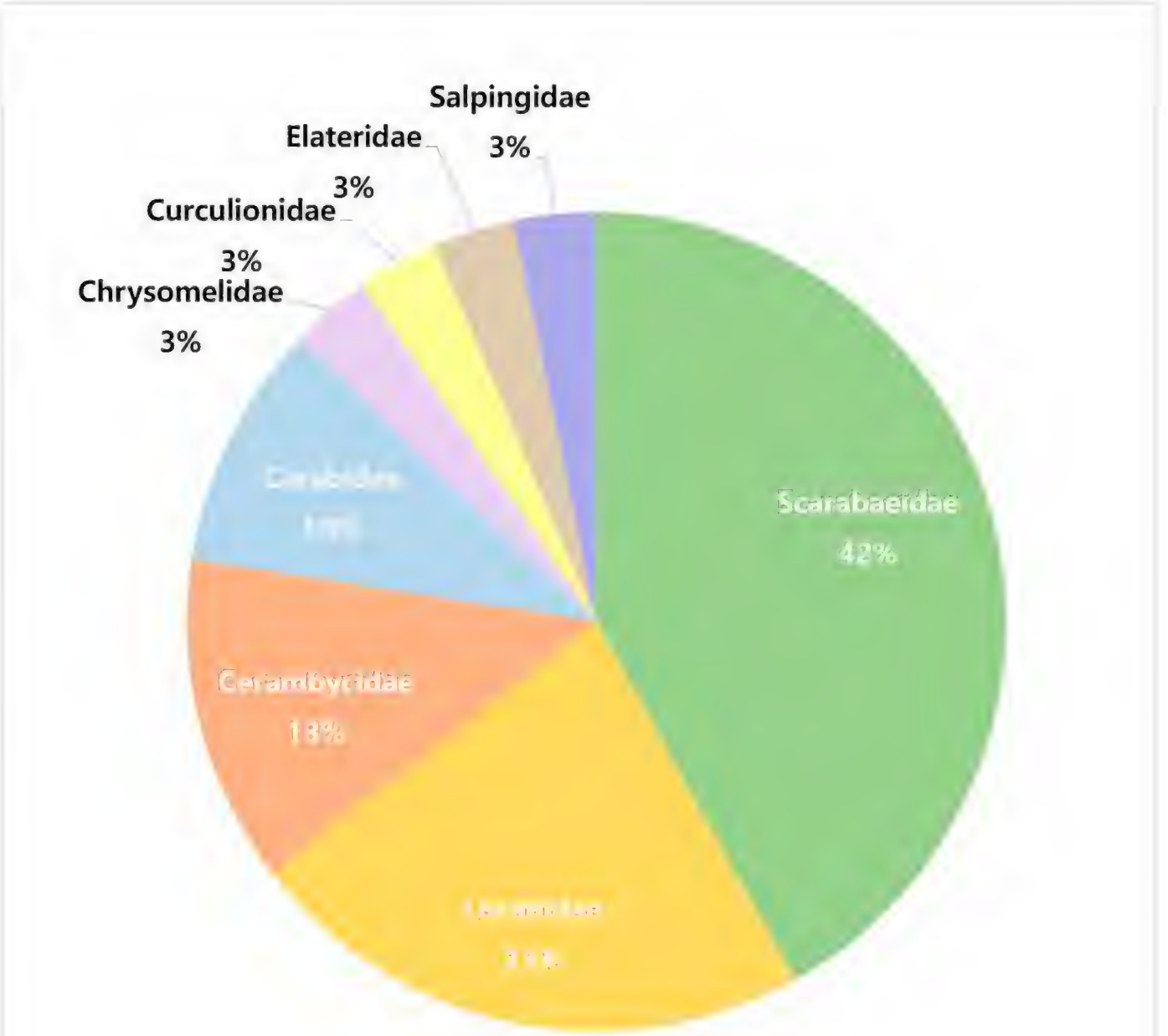

Figure 13. doi

Composition of intersex and gynandromorph cases in Coleoptera.

Amongst the three observed specimens, *P. fortunei* was classified as intersex, as all its body parts, including the genitalia, displayed female characteristics, except for the antennae, which exhibited ambiguous male traits. In contrast, *D. titanus castanicolor* and *T. dichotomus septentrionalis* were categorised as gynandromorphs, exhibiting the most common patterns, patchy type and bilateral type, respectively (Fusco and Minelli 2023).

Limited research has been conducted on the mating behaviour of intersex and gynandromorphic insects, though some cases have been reported in certain insect orders, including Ephemeroptera, Orthoptera, Phasmatodea, Hemiptera, Diptera and Hymenoptera (Barth and Bell 1971, Mertins and Coppel 1971, Witherell 1971, Cook 1978, Seow-Choen 1995, Vance 1997, Maeno and Tanaka 2007, Sampson et al. 2010, Matsuo et al. 2018). For example, a gynandromorphic individual of *Bombus ignitus*

(Smith, 1869) approached a virgin female in a laboratory setting, but took longer than typical males to attempt mating and ultimately failed (Matsuoka 2013). Similarly, a gynandromorphic individual of *Osmia ribifloris biedermannii* Michener, 1936 attempted mating, but was unsuccessful (Sampson et al. 2010). Although these individuals may exhibit sex-specific behaviour, they generally fail to achieve successful mating.

Several cases of gynandromorphic or intersex individuals have been reported in beetles (Table 1). However, no study has yet been published regarding their mating behaviour. This study aimed to assess mating behaviour during controlled breeding attempts. Unfortunately, all gynandromorphic individuals perished before observations could be made, limiting the study to *P. fortunei*. When one intersex individual and one typical female were housed together, only aggressive interactions were observed and no mating behaviour was recorded.

Behavioural studies of intersex and gynandromorphic individuals are essential for gaining a deeper understanding of their behaviour. Additionally, such studies can provide valuable insights into their social interactions and reproductive potential under both natural and experimental conditions. Therefore, in addition to reporting intersex and gynandromorphic cases, future research should assess their behavioural interactions with typical males or females.

The compilation of our research findings and list updates identified 31 species across eight families (Table 1). Scarabaeidae accounts for the largest proportion (42%), followed by Lucanidae (23%), Cerambycidae (13%) and Carabidae (10%) (Fig. 13). However, these figures may be limited, as they are based solely on published literature.

One factor contributing to this limitation is that intersex and gynandromorphic individuals, particularly within Coleoptera, often attract collectors due to their rarity and distinctive appearances, leading to high market prices (e.g. on platforms like eBay or specialised insect trading websites). Many such specimens are likely held in private collections, resulting in numerous undocumented cases in scientific literature.

Another factor is that Scarabaeidae and Lucanidae species, which together account for 65% of these cases (Fig. 13), are especially popular as pets (e.g. stag beetles and rhinoceros beetles) (Kawahara 2007). The high demand for these beetles has led to large-scale breeding in commercial facilities and by private breeders, increasing the likelihood of discovering intersex or gynandromorphic individuals compared to other beetle families.

Moreover, in taxa with less pronounced sexual dimorphism, intersex or gynandromorphic individuals may go unnoticed. As a result, it is likely that many undocumented cases exist not only in highly diverse families such as Staphylinidae, Carabidae and Curculionidae, but also in taxa with subtle sexual dimorphism, such as Coccinellidae. Therefore, to improve our understanding of gynandromorphism and intersex phenomena, systematic research and documentation of these taxa are essential.

Conclusion

This study reviewed and documented 31 beetle species exhibiting intersex or gynandromorphic traits across eight families, including an intersex individual of *P. fortunei* and two gynandromorphic individuals of *D. titanus castanicolor* and *T. dichotomus septentrionalis*. Despite the continuous reporting of these cases, significant gaps remain in our understanding of these phenomena, particularly regarding their genetic mechanisms, developmental processes and behavioural implications. To fully comprehend intersex and gynandromorphic occurrences in beetles, an integrated approach combining molecular, genetic and behavioural studies is essential. Future research should focus on behavioural observations to assess their reproductive potential and interactions with typical individuals. Additionally, uncovering the ecological and evolutionary significance of these conditions could provide deeper insights into insect development and sex determination. Expanding systematic research and documentation will be crucial in advancing our knowledge of these rare and fascinating phenomena.

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Supplementary material

Suppl. material 1: Breeding cases and environments used for behavioural observation doi

Authors: Donguk Kim, Sang Eun Hyun, Kwang Shik Choi
Data type: images
Brief description: A: breeding case, B: breeding environment setup.
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